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Comparison of thermal performance of BCHP system with latent thermal energy storage in different locations

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Abstract

Building cooling, heating and power (BCHP) is an integrated energy system to provide the three energy commodities, which is characterized by cascading utilization of primary energy and high energy efficiency. Latent thermal energy storage (LTES) is a promising technology to smoothen the fluctuating loads, and improve the system efficiency due to the isothermal property during phase change process and the high energy storage density. This paper aims at studying the influences of LTES location on BCHP system, in the upstream or downstream of waste heat recovery unit, with consideration of partial load performance of equipment. Firstly, a general model is presented for a typical BCHP system working in winter, consists of gas turbine (GT), absorption heat pump (AHP), and LTES unit. Based on the assumption of infinite number of transfer unit (NTU) of LTES, the comparison of the two designs is conducted in terms of primary energy consumption (PEC) and equipment capacity for an office in Beijing. Then, the influences of the limited heat transfer area of LTES are analyzed. The results show that the addition of LTES can significantly reduce the PEC and equipment capacity because it enables the GT work efficiently. In addition, the choice of the LTES in the downstream of AHP is preferred when assuming infinite NTU of LTES. However, when considering the limited heat transfer area, the heat transfer temperature difference makes the downstream choice less advantageous.

Keywords: Tri-generation; Energy storage; Phase change material; Absorption heat pump; Number of transfer unit

1. Introduction

Building heating, cooling, and power (BCHP) system is regarded as an efficient technology to produce the three energy commodities simultaneously for buildings, for the energy cascade utilization. However, the mismatch between the energy supply and demand, caused by the loads fluctuation on user side, makes the system operate under partial loads and leads to a low energy efficiency [1].

Some case studies showed that the combination of BCHP and thermal energy storage (TES) was helpful to reduce the equipment capacity, make the system work smoothly and reduce the primary energy consumption [2]. Latent thermal energy storage (LTES) is a promising option for its isothermal property during phase change process and high energy storage density [3].However, there is lack of comparison of

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thermal performance of BCHP systems with different location of LTES, in the upstream or downstream of waste heat recovery unit.

This paper aims at studying the influences of LTES location on BCHP system with consideration of partial load performance of equipment, in terms of primary energy consumption (PEC) and equipment capacity for a hotel in Beijing.

2. BCHP system model

Fig. 1 shows a typical BCHP system, which consists of gas turbine (GT), absorption heat pump (AHP) , heat exchanger (HX)and a candidate LTES in different location. The GT produces electricity, with the exhaust firing the AHP to provide heat to the air conditioning system. The system works following heat load, which means the GT and AHP work exactly to satisfy the heat load, while the excess and supplementary electricity is exchanged with grid.

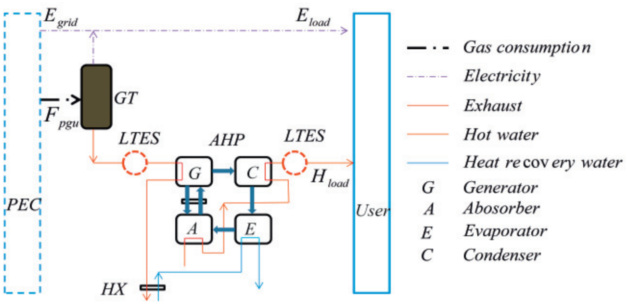

Fig. 1. BCHP system scheme and energy flows

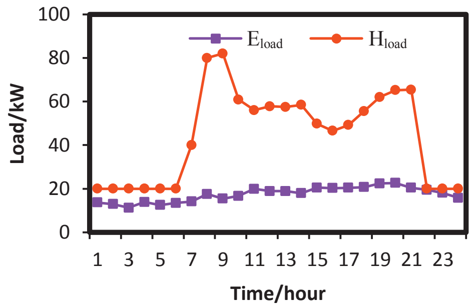

Fig. 2. Daily load profiles of an office in winter

Generally, the GT works unsteady according to loads, which leads to partial load operation and low efficiency. In this paper, the partial load model, including normalized fuel energy $\overline{F}_{pgu}$, exhaust flow $\overline{m}_{exhaust}$, and exhaust temperature $\overline{T}_{exhaust}$, is fitting from manufacturer data [4].

$$\overline{F}_{pgu} = 0.65 \cdot \overline{E}_{pgu} + 0.35 \tag{1}$$

$$\overline{m}_{exhaust} = 0.67 \cdot \overline{E}_{pgu} + 0.33 \tag{2}$$

$$\overline{T}_{exhaust} = 0.35 \cdot \overline{E}_{pgu} + 0.65 \tag{3}$$

where, $\overline{E}_{pgu}$ is the power output normalized by the rated power.

The AHP is driven by the exhaust of high temperature, transferring heat from low temperature resource such as environment, to hot water. For a given machine, the AHP coefficient of performance is determined by the work condition of the four temperatures.

$$COP = \eta \cdot \frac{T_{gen} - T_{evap}}{T_{gen}} \cdot \frac{T_{heat}}{T_{heat} - T_{evap}} \tag{4}$$

where, T_{gen}, T_{evap}, T_{heat} indicates generating temperature, evaporating temperature, and hot water supply temperature, respectively (K) ;and η is correction factor.

The LTES stores/releases heat according to the loads, allowing the GT work steadily with high efficiency. It's assumed that the phase change material (PCM) maintains its melting point during charge/discharge process. When infinite number of transfer unit (NTU) is assumed, the heat transfer fluid (HTF) outlet temperature equals the melting temperature of PCM. With a limited size of heat transfer design of LTES, the finite NTU affects the HTF outlet temperature during charge/discharge process.

$$\varepsilon = 1 - \exp(-NTU) \tag{5}$$

$$T_{c,o} = T_{c,i} - \varepsilon \cdot (T_{c,i} - T_m) \tag{6}$$

$$T_{d,o} = T_{d,i} + \varepsilon \cdot (T_m - T_{d,i}) \tag{7}$$

where, $T_{c,i}$ and $T_{c,o}$ represent HTF inlet and outlet temperature during charge process (K), respectively, while $T_{d,i}$ and $T_{d,o}$ represent HTF inlet and outlet temperature during discharge process (K), respectively; and T_m is the melting temperature of PCM (K); ε is the effectiveness of heat exchanger.

3. Illustrative example

The BCHP system is designed to meet the electricity and heat load of the air conditioning system for an office in Beijing in winter, and the typical daily load profile is shown in Fig.2. Different system schemes, with LTES located in the downstream or the upstream of AHP, are compared in terms of their thermal performance.

3.1. Comparison based on infinite NTU assumption

Comparison of different system scheme is conducted under the assumption of enough heat transfer area between the HTF and LTES during charge or discharge process. The system performance can be summarized in Table.1, in terms of PEC and the equipment capacity.

Table 1. System performance comparison

BCHP system	PEC (*kWh*)	GT capacity (*kW*)	AHP capacity *(kW)*
Without LTES	2312.5	54.9	82.0
With LTES(upstream)	1612.6	29.4	82.0
With LTES(downstream)	1596.8	28.8	48.3

It is showed that compared to system without LTES, the system with LTES in upstream and downstream of AHP saves by 30.2% and 30.9% for the PEC, 46.6% and 47.5% for the GT capacity, 0% and 41.1% for the AHP capacity, respectively. Therefore, while LTES generally improve the system performance for the case studied, the LTES in the downstream of AHP is preferred than the upstream one. The main reason is that the AHP has a relatively high generation temperature and COP with LTES in downstream.

3.2. Comparison considering the influence of finite NTU

In reality, the heat transfer area in LTES between HTF and PCM is limited, so the outlet temperature of HTF varies with the NTU during charge and discharge process. From Fig.3, it can be gotten that as the NTU decreases, the advantage of downstream option over upstream option decreases, till the upstream option saves more PEC. The main reason is that the COP of AHP is generally more sensitive to condense temperature than generation temperature.

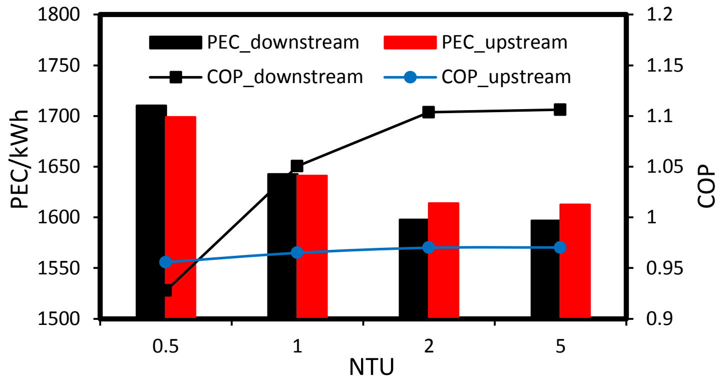

Fig. 3. System performance varying with NTU

4. Conclusion

In this paper, the comparison is conducted between the system of LTES in the upstream and the downstream of AHP. It's shown that the downstream option is preferred because more heat is recovered from exhaust and higher COP of AHP is reached, when enough NTU is invested to the LTES. The advantage of the downstream option is reducing with decreasing NTU, for the COP of AHP is more sensitive to condense temperature than generation temperature. Similar conclusion can be applied to the general BCHP systems with AHP or absorption chiller as heat recovery unit and LTES as TES unit.

Acknowledgements

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Biography

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